

GPS/IMU CLOCK SYNCHRONIZATION PARTICULARLY  
FOR DEEP INTEGRATION VECTOR TRACKING LOOP

Technical Field of the Invention

5           The present invention relates to the  
synchronization of clocks used in a navigation system  
that includes an inertial measurement unit, a global  
positioning system, and/or a navigation computer.

10   Background of the Invention

A navigation system frequently relies on an  
inertial measurement unit (IMU) and a global positioning  
system (GPS) that interface with a navigation computer to  
provide navigation control and/or guidance of a craft  
15   such as an airplane, missile or submarine. In operation,  
the navigation system may assume control of the GPS  
tracking loops by use of a Kalman filter, which is  
commonly referred to as Deep Integration. Because of the  
precise nature of how the tracking loops are driven, the  
20   navigation system as described above requires precise  
alignment of the clock signals incorporated within the  
global positioning system, the inertial measurement unit,  
and the navigation computer. Furthermore, because of  
varying computational performance in the navigation  
25   computer, a phase adjustment mechanism is desirable in  
order to precisely adjust the time alignment of the data  
from the inertial measurement unit, the data from the

global positioning system, and the tracking loop  
commands.

The present invention is directed to an  
arrangement that provides clock synchronization for a  
5 navigation system. Additionally or alternatively, the  
present invention may also be arranged to adjust the time  
alignment of the data from the inertial measurement unit,  
the data from the global positioning system, and the  
tracking loop commands of the navigation system.

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#### Summary of the Invention

According to one aspect of the present  
invention, a navigation system comprises an inertial  
measurement unit, a navigation computer, and a clock  
15 controller. The inertial measurement unit has a clock  
and the navigation computer has a clock. The clock  
controller enables only the navigation computer to be  
clocked by the clock of the navigation computer at times,  
and the clock controller enables both the navigation  
20 computer and the inertial measurement unit to be clocked  
by the clock of the navigation computer at other times.

According to another aspect of the present  
invention, a navigation system comprises an inertial  
measurement unit, a navigation computer, and a clock

controller. The inertial measurement unit has a first clock and a first switch, and the navigation computer has a second clock and a second switch. The clock controller controls the first and second switches so as to  
5 selectively supply a clock signal from the second clock to only the navigation computer and to both the navigation computer and the inertial measurement unit.

According to still another aspect of the present invention, a method comprises the following:  
10 supplying a first clock signal from a clock of a navigation computer only to components of the navigation computer in response to a first condition; supplying the first clock signal from the clock of the navigation computer to components of the navigation computer and to  
15 components of an inertial measurement unit in response to a second condition; and, supplying a second clock signal from a clock of a GPS receiver to components of the GPS receiver, to components of the navigation computer, and to components of the inertial measurement unit in  
20 response to a third condition.

#### Brief Description of the Drawings

These and other features and advantages will become more apparent from a detailed consideration of the

invention when taken in conjunction with the drawings in which:

Figure 1 is a schematic diagram of a navigation system including a clock selection feature according to  
5 an embodiment of the present invention; and,

Figure 2 illustrates a phase adjustment enhancement of the clock selection feature shown in Figure 1.

10 Detailed Description

A navigation system 10 is shown in Figure 1 and is used to provide navigation control and/or guidance of a craft such as an airplane, missile or submarine. In terms of an aircraft, the navigation system 10 may be  
15 used to automatically control the flight of the aircraft, and/or the navigation system 10 may be used to provide read outs to the pilot so as to guide the pilot in the flight of the aircraft.

The navigation system 10 may include one or  
20 more of an inertial measurement unit 12, a navigation computer 14, and/or a global positioning system (GPS) receiver 16. In the embodiment shown in Figure 1, the navigation system 10 includes the inertial measurement unit 12, the navigation computer 14, and the GPS receiver

16. The inertial measurement unit 12 normally includes a clock 18, the navigation computer 14 normally includes a clock 20, and the GPS receiver 16 normally includes a clock 22.

5           In addition to the clock 18, the inertial measurement unit 12 includes components such as inertial sensors and electronics. The inertial sensors, for example, may be accelerometers and/or gyros. The electronics of the inertial measurement unit 12 control  
10 the inertial sensors and suitably process the signals from the inertial sensors. In addition to the clock 20, the navigation computer 14 includes components such as hardware and software to perform various functions and computations in support of the guidance and/or control of  
15 a craft. In addition to the clock 22, the GPS receiver 16 includes components useful in determining a global position of a craft.

          When the navigation system 10 includes only the inertial measurement unit 12, or when only the inertial  
20 measurement unit 12 is functioning properly, the clock 18 is used to provide clock signals for clocking the components of the inertial measurement unit 12. When the navigation system 10 includes only the navigation computer 14, or when only the navigation computer 14 is

functioning properly, the clock 20 is used to provide clock signals for clocking the components of the navigation computer 14. When the navigation system 10 includes only the GPS receiver 16, or when only the GPS receiver 16 is functioning properly, the clock 22 is used to provide clock signals for clocking the components of the GPS receiver 16.

However, when combinations of more than one of the inertial measurement unit 12, the navigation computer 14, and the GPS receiver 16 are present and are functioning properly, the vector tracking loop of the navigation system 10 requires precise alignment of the clocks 18, 20, and/or 22 of the inertial measurement unit 12, the navigation computer 14, and/or the GPS receiver 16. Therefore, the clock functions of the selected combination of the inertial measurement unit 12, the navigation computer 14, and the GPS receiver 16 must be synchronized.

Accordingly, the navigation system 10 includes a clock controller 24. The clock controller 24 may comprise, for example, a field programmable gate array. The clock controller 24 is controlled, such as by the navigation computer 14, to select one of the clocks 18, 20, and 22 to provide the clock signals for all of the

components selected for inclusion or operation in the navigation system 10 (i.e., the inertial measurement unit 12, the navigation computer 14, and/or the GPS receiver 16).

5           To perform this clock selection function, the clock controller 24 is coupled to a switch 26 in the inertial measurement unit 12 and to a switch 28 in the navigation computer 14. The switch 26 has terminals 26a and 26b, and the switch 28 has terminals 28a and 28b.

10       The switches 26 and 28 may be mechanical switches, electronic switches, magnetic switches, etc. When the GPS receiver 16 is included in the navigation system 10, the clock controller 24 is also coupled so as to receive the clock signal from the clock 22 of the GPS receiver  
15       16.

          With this arrangement, the clock controller 24 selects one of the clocks 18, 20, and 22 to provide the clock signals to the components depending upon the combination of the inertial measurement unit 12, the  
20       navigation computer 14, and/or the GPS receiver 16 selected to be included or active in the navigation system 10. For example, if the inertial measurement unit 12, the navigation computer 14, and the GPS receiver 16 are all active in the navigation system 10, the clock

controller 24 operates the switch 26 against its terminal 26b and operates the switch 28 against its terminal 28a. Accordingly, the clock controller 24 supplies the clock signal from the clock 22 of the GPS receiver 16 to the  
5 inertial measurement unit 12 through the switches 26 and 28 and to the navigation computer 14 through the switch 28. In this configuration, the clock 22 of the GPS receiver 16 supplies clock signals to clock the inertial measurement unit 12, the navigation computer 14, and the  
10 GPS receiver 16. Therefore, clock functions of the inertial measurement unit 12, the navigation computer 14, and the GPS receiver 16 are synchronized.

Alternatively, if only the inertial measurement unit 12 and the navigation computer 14 are active in the  
15 navigation system 10, the clock controller 24 operates the switch 26 against its terminal 26b and operates the switch 28 against its terminal 28b. Accordingly, the clock controller 24 controls the switches 26 and 28 so that the clock signal from the clock 20 of the navigation  
20 computer 14 is supplied to the inertial measurement unit 12. In this configuration, the clock 20 of the navigation computer 14 supplies clock signals to clock the inertial measurement unit 12 and the navigation computer 14. Therefore, clock functions of the inertial



measurement unit 12 and the navigation computer 14 are synchronized. In this configuration, the clock controller 24 does not pass through the clock signal from the clock 22.

5                   Therefore, clock synchronization is accomplished by enabling the navigation computer 14 to utilize a switchable clock input, and by enabling the inertial measurement unit 12 to utilize a clock source from the navigation computer 14. Normally, the  
10 navigation computer 14 uses its own oscillator (the clock 20) as its time source. However, to achieve better alignment with inertial data, the inertial measurement unit 12 can be clocked by the clock 20 of the navigation computer 14. Furthermore, to adequately take control and  
15 drive the tracking loops of the GPS receiver 16 by use of Deep Integration, the clocking functions of the inertial measurement unit 12, the navigation computer 14, and the GPS receiver 16 preferably should be coupled to a single clock source. This coupling is achieved by sharing the  
20 clock 22 of the GPS receiver 16 with the navigation computer 14 and also with the inertial measurement unit 12.

                  The navigation computer 14 uses its own oscillator, the clock 20, for operation when the inertial

measurement unit 12 is not present or has failed. The navigation computer 14 can share its oscillator, the clock 20, with the inertial measurement unit 12 when the inertial measurement unit 12 is present but the deep  
5 integration of the GPS receiver 16 is not present or is not being executed. When deep integration provided by the GPS receiver 16 is present and is being executed, the navigation computer 14 can be configured to use the clock signal from the clock 22 of the GPS receiver 16, and the  
10 navigation computer 14 is also configured to send this clock signal to the inertial measurement unit 12 for Deep Integration operation.

Moreover, because of varying computational performance in the navigation computer 14, a phase  
15 adjustment mechanism may be provided to precisely adjust the time alignment of the inertial data from the inertial measurement unit 12, the GPS data from the GPS receiver 16, and the tracking loop commands provided by the navigation computer 14. Accordingly, a phase controller  
20 30 as shown in Figure 2 is provided in the clock controller 24 so as to adjust the phase of the clock signal provided by the clock 22 of the GPS receiver 16 to the inertial measurement unit 12 and the navigation computer 14.

The phase controller 30 includes a count down register 32 that receives a clock input from a clock 34 that operates at a frequency that is  $nf_{\text{GPS}}$ , where  $f_{\text{GPS}}$  is the frequency of the clock signal provided by the clock 22 of the GPS receiver 16, and where  $n$  is preferably an integer. A typical value for  $n$  is 1000, but  $n$  can be set to any value that provides the required precision in phase adjustment.

Also, an initial count is provided to an input 36 of the count down register 32. This initial count may be user defined. The initial count is typically set to the minimum phase delay until observation of the system performance is made to determine the optimum phase delay. For example, the optimum phase delay can be determined by experimental means in a lab environment by executing test software to observe the relationship between when commands are sent to the tracking loops of the GPS receiver 16 and when the results of those commands are seen. The optimum phase delay can also be set at run time in a similar fashion during the initialization phase of the software.

When the count down register 32 counts down from this initial value to a count of zero, the count down counter 32 provides an output pulse. Finally, an

input 38 of the clock controller 30 receives the clock signal from the clock 22 of the GPS receiver 16.

Accordingly, each time that the count down register 32 receives a clock pulse at the input 38 from the clock 22 of the GPS receiver 16, the count down register 32 is reset to the initial count provided at the input 36. Thereafter, the count down register 32 is clocked by the clock signal from the clock 34 to count down to zero from the initial count. When the count down register 32 has counted down to zero, the count down register 32 provides an output clock pulse which is supplied as the clock output of the clock controller 24. In this manner, the clock pulse at the input 38 from the clock 22 of the GPS receiver 16 is delayed by a delay amount according to the initial count and the frequency  $nf_{GPS}$  of the clock signal from the clock 34. This delay amount adjusts the phase of the clock signal from the clock 22 of the GPS receiver 16 in order to precisely adjust the time alignment of the inertial data from the inertial measurement unit 12, the GPS data from the GPS receiver 16, and the tracking loop commands provided by the navigation computer 14.

Certain modifications of the present invention have been discussed above. Other modifications will

occur to those practicing in the art of the present invention. Accordingly, the description of the present invention is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the  
5 best mode of carrying out the invention. The details may be varied substantially without departing from the spirit of the invention, and the exclusive use of all modifications which are within the scope of the appended claims is reserved.